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# Complex magnetic response in magnetic tunnel junctions determined via magnetic and transport measurements

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We have studied the low frequency complex magnetization dynamics in $Co/Al_2O_3/Ni_{80}Fe_{20}$ magnetic tunnel junctions (MTJs) at temperatures between 4.2K and 300K. The measurements were carried out by using two different experimental techniques. The first method probes directly magnetic properties via DC magnetization and AC susceptibility, while the second one measures AC magnetization dynamics of the ferromagnetic electrodes near the cross area, which is related to the tunnelling resistance.

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## INTRODUCTION

Magnetic tunnel junctions (MTJ) with highly reliable magnetoresistance [1] are promising candidates for non-volatile memory, next generation of magnetic field sensors hard drive heads as well as important parts of more complicated magnetic nanostructures [2]. It was found recently that the magnetic domain walls (DWs) formed in the magnetic electrodes and correspondingly within cross area, may significantly affect operation of the MTJs, resulting in some cases even in long term degradation of the devices [3]. In addition, it is known that DWs strongly influence the noise of the magnetoresistive sensors [4, 5]. In their study of magnetic noise in magnetic multilayers Hardner et al. [4] proposed a simple method for evaluating dynamic magnetic properties of the systems with giant magnetoresistance (GMR) by studying the response in the electron transport of the structure subject to both DC and AC magnetic fields. Although DC transport and magnetic properties of MTJs

are reasonably well understood, little is known [6] about the AC magnetic and transport responses of MTJs. Knowledge of dynamic magnetic properties of MTJs could provide information about mechanisms of magnetization reversal, domain wall mobility, disorder and other characteristics of MTJs, important both for fundamental and applied research, and not accessible in the DC experiments. Indeed, a method proposed for investigation of the DW dynamics in magnetic nanowires by employing GMR effect as a detector [7], could not be directly applied to the standard MTJs because their geometry permits two-dimensional movement of the DWs. A recent demonstration of the applicability of the tunnel magnetoresistance (TMR) signal for analysis of the DWs structure in MTJs, completed by magnetic force microscopy [8] or magnetooptic analysis [9], reveals some interesting static, but not dynamic properties of the domain walls. This paper presents an investigation of the low frequency (below $100Hz$) AC magnetization response of MTJs studied both via direct magnetic measurements and by using the TMR effect as spin detector.

## SAMPLE PREPARATION AND EXPERIMENTAL SETUP

Details of sample preparation and characterization were described previously in [1]. In brief, a $1nm$ of $Si$ is deposited on a glass substrate at $77K$ as a seed layer . Then cobalt (hard layer with thickness of $8nm$) and aluminium (depending on the samples the thickness of $Al$ was varied between $0.6nm$ and $1nm$ ) layers were deposited at the same temperature. At the next stage, the samples were warmed to room temperature, and oxidation of the barrier was produced by glow discharge, followed by deposition of the permalloy layer (soft layer with thickness of $10nm$), a magnetic field, of about $50Oe$, was applied while the deposition of both magnetic electrodes, in order to fix the magnetic anisotropy of the layers. In the present study we used a sample with a cross area definition of $200 \times 200 \mu m$, the room temperature (RT) resistance is about 1 k$\Omega$, and the magnetoresistance is 12% (RT) and 18% (4.2K).

Direct DC magnetization ($M$) and AC magnetic properties ($\chi'_M$ and $\chi''_M$ were studied by using a MPMS (Quantum Design) with the magnetic field directed along the easy axis of magnetization. Sample used in this experiments have the same dimensions as the one used in the transport measurements.

In order to measure the magnetic dynamic response via electron transport we developed a setup similar to ref. [4]. Our sample was introduced in an Oxford cryostat which allows

to vary the temperature from $300K$ to $4.2K$. The magnetic field was applied by using two solenoids placed outside the vacuum chamber. A DC current source controls the magnetic field $H$, directed along the easy axis of the sample. The AC source generates a small sinusoidal magnetic field with a frequency $f$ and an amplitude $\delta H$ parallel to the DC field. The sample has been biased by a DC current equal to $100\mu A$ in all the presented experiments. The AC signal generated in the sample as a response to the external AC magnetic field was detected by a lock-in amplifier and the DC response by a nanovoltmeter. In this way we obtain the in-phase ($X = \chi'_V(f) \cdot \delta H$) response which is proportional to the derivative $\frac{dV}{dH}$, and the imaginary response ($Y = \chi''_V(f) \cdot \delta H$) reflecting magnetic looses. In the following this method will be called as the indirect method.

## RESULTS AND DISCUSSION

Figure 1 presents typical $X$ and $Y$ voltage responses obtained in the indirect method, at a drive frequency of $77Hz$, at a temperature $T = 77K$ and at two different excitations, when the DC field is varied. The curves were averaged over 6 measurements. The inset
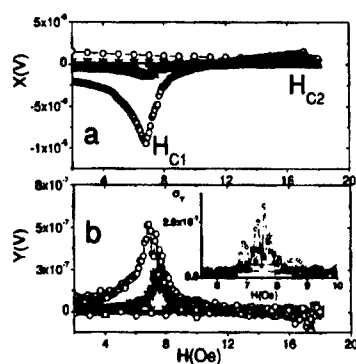


Figure 1: (a) Typical in-phase signal $X$ and (b) out of phase signal $Y$ as functions of the applied DC field for two different amplitude excitations $\delta H = 50mOe$ and $7mOe$, at $77K$ and $f = 77Hz$. Inset in (b) shows typical deviation ($\sigma_Y$) of the curve, the increase of this magnitude after the maximum indicates the change of the behavior of the losses in the permalloy layer from rotations to magnetization jumps.
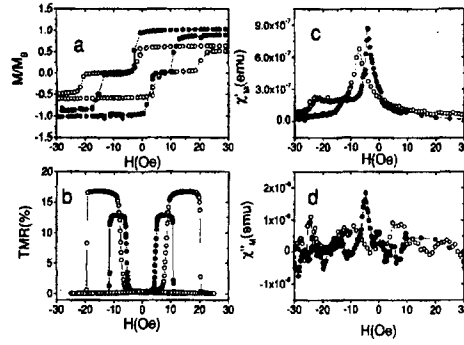
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Figure 2: Tunnelling magnetoresistance of the MTJ used in the noise measurements and magnetic properties of a MTJ with the same composition as the one used for the indirect measurements. At $300K$ (closed points) and $4.2K$ (open points). Panel (a) shows the magnetization of the junction. Graph (b) presents tunnelling magnetoresistance defined as $TMR = [R_{AP} - R_P]/R_{AP}$. Panels (c) and (d) show AC susceptibility measurements at $f = 6Hz$ and $\delta h = 0.2 Oe$. Part (c) is the real part and (d) is the imaginary part.

shows the corresponding dispersion for such averaging. The anomalies at the coercive fields $H_{C1} = 6 \pm 0.5G$ and $H_{C2} = 16 \pm 1G$ are related to orientation transitions in the cobalt and permalloy. We should also point out that typically the shape of the maximum in losses obtained via TMR is non-symmetric. Usually one observes a gradual increase in $\chi_V''$ when approaching $H_{C1}$ (i.e. for $H < H_{C1}$) followed by an enhancement of the dispersion when $H \gtrsim H_{C1}$. This could be due to a gradual growth of the small domains for $H < H_{C1}$, followed by the process of converting them into larger ones, corresponding to a decrease in $\chi_V''$ and an enhanced Barkhausen noise.

Figure 2 shows the data obtained in the magnetic measurements at RT (closed points) and $4.2K$ (open points). Part a the DC magnetization, c and d are the real and the imaginary part of the AC susceptibility, respectively. Panel b is the magnetoresistance of the sample used in the transport measurement. Coercive fields in both samples are nearly the same.

Comparison of the data obtained in both methods points out some similarities and differences between magnetic susceptibility and the transport measurements. Independently of temperature, frequency or drive amplitude, for both signals we observe two anomalies

in their real parts, reflecting coercive fields $H_{C1}$ and $H_{C2}$ of permalloy and cobalt (Fig. 1a and 2c). The deep of the minimum in between the two transitions in the real part of the AC susceptibility depends on the degree of antiparallel alignment and, in addition, maybe affected by the edge effects coming from the electrodes.

The direct out-of phase measurements shows that the maximum in $\chi''_M(f)$, which corresponds to the losses during magnetization reversal in permalloy, disappears for temperatures bellow $77K$ (see Fig. 2d which compares data at $300K$ and $4.2K$). The situation is different for the indirect method where the maximum in $\chi''_V(f)$ near $H_{C1}$ is clearly observed down to $4.2K$ (only data for $77K$ is shown here). The different behavior observed at low temperature is due to the sensitivity of the indirect method to the interface magnetization, because only few monolayers of permalloy, those near the barrier, contribute to the tunnel process. Therefore, one could argue that the DWs (or magnetic inhomogeneities) at the interface are free to move at low temperatures, when bulk domains became pinned. This results in the suppression of the maximum in the imaginary susceptibility at low temperature.

Finally we present the dependence of the complex response on the drive amplitude $\delta h$. Figure 3 shows the magnitude of the anomaly near the coercive field of permalloy layer as a function of the excitation amplitude. One can observe that, while the real part of
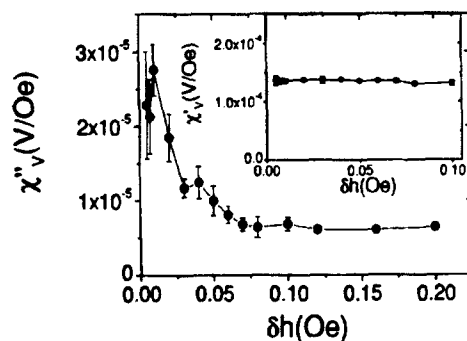


Figure 3: Dependence of the amplitude of the peak near the coercive field of permalloy at room temperature. Main part of the figure shows the amplitude of the peak in the imaginary part of the response. The inset shows the same quantity in the real part. Qualitatively similar behavior is observed at low temperatures.

the response changes linearly with $\delta h$ ($\chi'_V \sim constant$), the imaginary response strongly deviates from linearity at low excitations. Magnetoelastic coupling cannot explain this data [10], because it depends on the DWs velocity, which seems to be too high comparing with the dimension of the sample divided by the excitation frequency. One could also think in terms of a transformation of the DW type when $\delta h$ is increased. However, the thickness of our samples ($10 nm$) is too small to provide such a transition. We believe that the observed nonlinearity in the out-of phase response (with a linear in-phase response) could be due to a strong dependence of the relaxation time on $\delta h$. Presence of structural and magnetic disorder at the oxide-ferromagnet interface in magnetic tunnel junctions could be a reason for the strong dependence of the relaxation time on the excitation. Further work is, however, needed to clarify this issue.

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[1] J.S. Moodera , L.R. Kinder, T.M. Wong and R. Meservey, PRL, **74**, 3273 (1995).

[2] Stuart.S.P.Parkin, "Spin-Polarized Transport in Magnetic Tunnel Junctions and Magnetic Tunnel Transistors"- invited talk presented at Gordon Research Conference on magnetic nanostructures in Italy, 2002.

[3] S.Gider, et al., Science **281**, 797 (1998).

[4] H.T.Hardner, M.B.Weismann, M.B.Salamon, S.S.P.Parkin, Phys. Rev. **B48**, 16156 (1993).

[5] S. Ingvarson, G.Xiao, S.S.P. Parkin, W.J. Gallagher, G. Grinstein, R.H. Koch, PRL, **85**, 3289 (2000)

[6] P.Ripka, M.Tondra, J.Stokes, R.Beech, Sensors and Actuators, **76** , 225 (1999).

[7] T.Ono, H.Miyajima, K.Shigeto, K.Mibu, N.Hosoito, T.Shinjo, Science,.**284**, 468 ( 1999).

[8] C.Tuisan, M.Hehn, T.Dimopolous, K.Ounadjela, J. Applied Physics, **89**, 6668 ( 2001).

[9] O.Lenoble, M.Hehn, D.Lacour, A.Schuhl, D.Hrabovsky, J.F.Bobo, B.Diouf, A.R.Fert, Phys. Rev. **B63**, 05240 (2001).

[10] V.G.Bar'yakhtar, B.A.Ivanov, M.V.Chetkin, Sov. Phys. Usp. **28**, 583 ( 1985).

[11] N. Papanicolaou, Phys. Rev. **B55**, 12290 ( 1997).